רשות הפטנטים

מדינת ישראל
משרד המשפטים

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This 06-09-2011 היום

Asa Kling אסא קלינג
רשם הפטנטים
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158989	מספר: Number
20-11-2003	תאריך: Date הוקדם/נדחה Ante/Post-Dated

חוק הפטנטים, תשכ"ז-1967
Patent Law, 5727 - 1967

בקשה לפטנט
Application for Patent

אני, (שם המבקש, מענו ולגבי גוף מאוגד - מקום התאגדותו)
I, (Name and address of applicant, and in case of body corporate-place of incorporation)

ORMAT INDUSTRIES LTD.
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(באנגלית) (English)
HYBRID POWER SYSTEM FOR CONTINUOUS RELIABLE POWER AT LOCATIONS INCLUDING REMOTE LOCATIONS

hereby apply for a patent to be granted to me in respect thereof. מבקש בזאת כי ינתן לי עליה פטנט

*בקשת חלוקה - Application of Division	*בקשת פטנט מוסף - Application for Patent Addition	*דרישה דין קדימה Priority Claim		
*מבקשת פטנט from Application № ______ מס' dated ____ מיום	*לבקשה/לפטנט to Patent/Appl. № ______ מס' dated ____ מיום	מספר/סימן Number/Mark	תאריך Date	מדינת האיגוד Convention Country
*יפוי כח: כללי / ~~מיוחד - רצוף בזה /~~ עוד יוגש P.O.A.: general / ~~individual - attached /~~ to be filed later filed in case ______ הוגש בענין				
המען למסירת מסמכים בישראל Address for Service in Israel לוצאטו את לוצאטו ת.ד. 5352 באר שבע 84152 מספרנו: 16950/03				
חתימת המבקש Signature of Applicant *Luzzatto & Luzzatto* By: Attorneys for Applicant		היום 20 בחודש נובמבר שנה 2003 This 20 of נובמבר of the year 2003		

לשימוש הלישכה

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HYBRID POWER SYSTEM FOR CONTINUOUS RELIABLE POWER AT LOCATIONS INCLUDING REMOTE LOCATIONS

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HYBRID POWER SYSTEM FOR CONTINUOUS RELIABLE POWER AT LOCATIONS INCLUDING REMOTE LOCATIONS

BACKGROUND OF THE INVENTION

1. Technical Field

This invention relates to a method and apparatus for producing power, and more particularly, to a method and apparatus for producing ultra-reliable power with redundancy which requires little maintenance or supervision and with improved fuel consumption.

2. Background of the Invention

The requirements for reliable power supply are more and more stringent with the advance of modern industry, computer and telecommunications systems and with the increasing costs of non-supply electricity. This particularly applies for on-site generation of electricity, be it for grid connected and distributed generation or off-grid prime power supply at remote locations. The conventional solutions for providing high efficiency on-site generation of electricity include, for short periods of interruption, battery or flywheel uninterruptible power supply (UPS) systems are used; and for longer periods, engine driven generators such as diesel generators are used for both applications relying on grid power, as well as for distributed generation and off-grid applications. The short term standby power using batteries

has a distinct disadvantage when failure occur. This is especially true since there is no satisfactory diagnostic system to detect failures of batteries on standby: a single cell failure can cause failure of the whole battery pack. Expensive climate control and limited life are also drawbacks of battery systems. In addition, while flywheel systems do not have the diagnostic problem, the systems can support the load for even less time than the battery systems.

The diesel generators used for longer periods of standby operation, however, have problems of unreliable startups and require frequent maintenance and periodic overhaul. Fuel cells and stirling engines can also be used but fuel cells have too long of a startup process and these systems are still in the development stage and have no proven reliability.

Combined cycle power plants, on the other hand, i.e., a power plant having usually a gas turbine and a bottoming cycle power generating unit, have a quite high overall efficiency since heat contained in the exhaust gases of the primary power generating unit is utilized in the bottoming cycle power generating unit to produce electric power. However, the reliability of such systems can be questionable. For example, see the article "Raising the Reliability of Advanced Gas Turbines," Power, Vol. 146, No. 2, March/April 2002, which reports that there are several reliability issues that need to be addressed when using combined cycle power plants.

For power generation systems that supply remote telecommunications with high reliable off-grid power, several options are available including: multiple diesel generators (MDG), photovoltaics, photovoltaics combined with diesel generators, thermoelectric generators (TEG), and closed cycle vapor turbogenerators (CCVT).

Multiple diesel generators (MDG) with one generator operating and one or two generators on standby has an advantage in that these systems have low fuel consumption and can operate using liquid or gaseous fuel. A multiple diesel generator system, however, depends on the reliability of the start-up of a standby generator if the operating generator fails. This necessitates a large battery to be included in the system so that it can be used in the event that the standby generator does not start. Further, the included large batteries typically require climate control in the form of heating or air conditioning, thus increasing the complexity and fuel consumption of the system for a given load.

In photovoltaic systems, batteries are used to compensate for the hours/days without solar radiation. Batteries in photovoltaic systems are usually quite large and work on deep discharge cycles. Because of the deep discharge cycles nickel-cadmium are better suited in photovoltaic systems than lead acid batteries. The cost of nickel-cadmium batteries is very high. In addition to the high cost of batteries, the life-span of these batteries is usually less

than 10 years. Maintenance, vandalism and theft of the batteries of photovoltaic are additional concerns for photovoltaic systems.

Photovoltaic systems having a diesel generator back-up share the same problems as the previously-mentioned strictly photovoltaic systems, namely, cost, life-span and maintenance of batteries as well as risk of vandalism and theft. In addition, utilizing a diesel generator as a back-up power source can produce reliability issues as the system redundancy depends on an unreliable diesel engine start.

As far as thermoelectric generators (TEG) are concerned, the TEG system has the highest fuel consumption of any of the systems thus far discussed. The high fuel consumption is aggravated by the fact that a TEG system is a constant power device that requires a dummy load for dissipating any excess energy and, thus requiring additional fuel consumption due to the over-sizing of the unit, output variations due to ambient conditions or varying load requirements. If additional batteries are not used, the battery will not be properly charged and will require additional maintenance and manual charging during maintenance and thus the life span of the battery will decrease. Additionally, TEG systems have a high fuel consumption and the life span of a TEG system is typically less than 10 years.

A more recent development in providing reliable power to remote locations has been the introduction of fuel cells. A fuel

cell is an energy conversion device that generates electricity and heat by electrochemically combining a gaseous fuel and an oxidant gas via an ion conducting electrolyte. The main characteristic of a fuel cell is its ability to convert chemical energy directly into electrical energy without the need for heat conversion (i.e., converting heat to electric or mechanical power optimized in accordance with the Second Law of Thermodynamics), giving much higher conversion efficiencies than heat engines (e.g., engine generators, CCVTs or TEGs). A system having such fuel cells and a gas turbine for achieving high efficiencies has been proposed by Siemens Westinghouse, as indicated in their website. However, the fuel cell technology is not mature and the life and reliability of the fuel cells are not sufficient to maintain reliable remote power without a proven backup for when the fuel cell fails.

Finally, the closed cycle vapor turbogenerator (CCVT) systems have a fuel consumption which, although lower than the TEG system, is much higher than that of a diesel generator. Redundancy for these systems is usually achieved through the use of one or two operating CCVTs, with one CCVT on warm standby. Fuel consumption varies in accordance with the load but the use of two CCVTs each operating at half load consumes 20% more fuel than one load at 100% load. Usually the level of power production in remote locations is between 1 - 10 kW.

It is therefore an object of the present invention to provide

a new and improved method of and apparatus for providing ultra-reliable power wherein the disadvantages of high fuel consumption, unreliability, maintenance, use of batteries and the associated climate control (which increases the power consumption and maintenance, thus reducing the reliability) as outlined above are reduced or substantially overcome.

SUMMARY OF THE INVENTION

The present inventive subject matter is drawn to an apparatus that combines a fuel efficient, primary power generation unit system such as a high temperature fuel cell (e.g., molten carbonate fuel cell (MCFC)) with a secondary power unit that is a very high reliability closed cycle vapor turbine (CCVT) which operates according to a Rankine cycle using organic working fluid that is capable of producing approximately 5 - 15% of the electric power that is produced by the primary power unit and which is heated by rejected heat of the primary power unit, wherein working fluid in the vaporizer of the CCVT is heated by the heat rejected by the primary power unit.

The present inventive subject matter is thus drawn to a hybrid ultra reliable power generating system for supplying continuous reliable power at various locations, e.g. at remote locations, comprising: a primary power unit producing electric power, such as a high temperature fuel cell, e.g. molten carbonate fuel cell

(MCFC), that is supplied to a load; and a secondary power unit in the form of a closed cycle vapor turbine (CCVT) system, which operates according to a Rankine cycle using organic working fluid, which is capable of producing approximately 5 - 15% of the electric power that is produced by the primary power unit and which is heated by rejected heat of the primary power unit, wherein working fluid in the vaporizer of the CCVT is heated by the heat rejected by the primary power unit. By using such an arrangement, the full power requirements of the load are supplied by the hybrid ultra reliable power generating system during operation of the primary power unit. Preferably, the CCVT includes a burner that combusts the same fuel as the primary power unit and supplies sufficient heat so that the CCVT continues to produce approximately 5 - 15% of the power produced by said primary power unit to the load once the primary power unit stops operation.

The present invention also relates to a method for supplying continuous reliable power at locations including e.g. remote locations, comprising the steps of: providing a primary power unit producing electric power, such as a high temperature fuel cell (MCFC) that is supplied to a load; and providing a secondary power unit in the form of a closed cycle vapor turbine (CCVT) system which operates according to a Rankine cycle using organic working fluid, which is capable of producing approximately 5 - 15% of the electric power that is produced by the primary power unit and which is heated by rejected heat of the primary power unit, wherein working fluid in the vaporizer of the CCVT is heated by the heat rejected by the primary power unit. By using such an arrangement, the full power requirements of the load are supplied by the hybrid ultra reliable power generating system during operation of the primary power unit. Preferably, the method also includes the step of providing a burner in the CCVT that combusts the same fuel as the primary power unit and supplies sufficient heat so that the CCVT continues to produce approximately 5 - 15% of the power produced by said primary power unit to the load once the primary power unit stops operation.

BRIEF DESCRIPTION OF THE DRAWINGS

A description of the present inventive subject matter including embodiments thereof is presented and with reference to the accompanying drawings, the description is not meant to be

considered limiting in any manner, wherein:

Fig. 1 is a graphical representation of a conventional combined-cycle power plant;

Fig. 2 is a graphical representation of a hybrid power plant shown in conjunction with the present inventive subject matter;

Fig. 3 is a schematic diagram of an embodiment of the present invention; and

Fig. 4 is a schematic diagram showing an example of the general layout of an embodiment of the present invention.

Like reference numerals and designations in the various drawings refer to like elements.

DETAILED DESCRIPTION

Turning now to the Figures, Fig. 1 represents a conventional high-efficiency combined-cycle power plant that is well-known in the art. As can be seen from the figure, fuel is supplied to a primary power unit which produces nominal power output. The power output of the primary power unit is generally about 60-80% of the required load. Heat is also exhausted from the primary power unit and supplied to a bottoming power unit, wherein power is produced and supplied to the load. In the conventional combined-cycle power plant as shown in Fig. 1, the ability of the bottoming power unit to produce electricity depends on the exhausted heat from the primary power unit. In other words, if the primary power unit

suddenly stops working, the heat to the bottoming unit also stops and the bottoming power unit no longer is able to function.

The cascading heat from the primary power unit to the bottoming power unit increases the overall efficiency of the combined-cycle power plant in that the waste heat from the primary power unit is put to work by the bottoming power unit. In addition, an optional heater or a duct burner is sometimes provided for maintaining the output of the bottoming cycle power unit when the output of the primary power unit drops due to high ambient temperature (the output of the system is sensitive to the air temperature). The duct burner allows for a constant heat flow to be supplied to the bottoming power unit.

The hybrid power generating system of the present inventive subject matter, on the other hand, is graphically represented in Fig. 2. As can be seen from the figure, fuel is supplied to a primary power unit, such as a high temperature fuel cell, e.g. a Molten Carbonate Fuel Cell (MCFC), which produces nominal power output. The power output of the primary power unit is generally approximately 85 - 95% of the required load. Heat is also exhausted from the primary power unit and supplied to a secondary power unit, e.g. a closed cycle vapor turbogenerator (CCVT) system which operates according to a Rankine cycle using organic working fluid for producing approximately 5 - 15% of the electric power that is produced by the primary power unit, for a power level

preferably ranging from approximately 1 - 40 MW for the hybrid power generating system. Further, a burner that operates on the same fuel as the primary power unit is provided to supply heat to the secondary power unit once the primary power unit fails.

The ability of the rejected or exhausted heat from the primary power unit to supply heat to the secondary power unit during operation of the primary power unit contributes to the reliability and redundancy of the present inventive system. It is an important aspect of the present inventive subject matter that the secondary power plant be sized to be able to continue to supply 5 - 15% of the power produced by the primary power unit upon failure of the primary power unit. In accordance with the present inventive subject matter, the hybrid power generating system preferably also includes a rotating capacitor that improves its power factor.

Referring now to Figure 3, reference numeral 5 of Fig. 3 designates an embodiment of the present invention considered at present the best mode for carrying out the present invention. In this embodiment of the hybrid ultra reliable power generating system the primary power unit may be a high temperature fuel cell, in particular a molten carbonate fuel cell (MCFC), and the output is a direct current output. The embodiment represented by Fig. 3 has primary power unit 16 and a secondary power unit that is a closed cycle vapor turbogenerator (CCVT) system which operates according to a Rankine cycle operating on an organic working fluid

wherein the working fluid in the vaporizer of the closed cycle vapor turbogenerator (CCVT) system is heated by the exhaust gases of primary power unit 16.

Fuel is supplied to the primary power unit 16 by fuel supply line 14 via fuel valve 12. Fuel valve 12 is operatively connected to controller 26. Under normal operating conditions fuel valve 12 is open, allowing fuel to be supplied to primary power unit 16. Hot exhaust gases containing rejected heat of primary power unit 16 are supplied to vaporizer 58 by primary power unit exhaust line 20 where heat from the hot exhaust gases is transferred to the liquid in vaporizer 58 via heat exchange device 22. The exhaust gases from primary power unit 16 heat the working fluid in vaporizer 58 and vaporized working fluid is produced. This vaporized working fluid proceeds through vapor conduit 64 from vaporizer 58 to turbine 66 causing turbine 66 to do work by rotation. Generator 67 coupled to turbine 66 converts the rotational work produced into electrical power. In this embodiment, the electrical output of generator 67 is in the form of alternating current (AC) electricity. Rectifier 82 rectifies the AC output of generator 67 into a direct current (DC) output prior to the same being supplied to the AC load via an inverter. The expanded working fluid vapor exhausted from turbine 66 is supplied by expanded working fluid vapor exhaust conduit 68 to condenser 70. The expanded working fluid vapor is condensed in condenser 70 and condensate produced is

returned to vaporizer 58 through return conduit 71 via pump 72. Cooled exhaust gases exit vaporizer 58 via exhaust pipe 24. The rejected heat in the exhaust gases and used in the CCVT is sufficient to produce approximately 5 - 15% of the power that is produced by the primary power unit. By using such an arrangement, the full power requirements of the load are supplied by the hybrid ultra reliable power generating system during operation of the primary power unit.

The power produced by primary power unit 16 is sensed by sensor 21. Sensor 21 is connected to controller 26 which monitors power produced by primary power unit 16. Under normal operating conditions, the power produced by primary power unit 16 is substantially sufficient for supplying 85 - 95% of the desired load and the power produced by the secondary CCVT system is approximately 5 - 15% of the electric power that is produced by the primary power unit. In this embodiment, the electrical output of primary power unit 16 is in the form of direct current (DC) electricity. Diode 83 maintains the flow of the DC output of primary power unit 16 to the AC load via an inverter.

In the event of a failure of primary power unit 16, sensor 21 detects the loss of power. Controller 26 closes fuel valve 12 which supplies fuel to primary power unit 16. Controller 26 then opens fuel valve 54 which is located on fuel supply line 52. Fuel supply line 52 supplies fuel to burner 56 of the secondary CCVT

system. Controller 26 sends a signal igniting burner 56. Burner 56 heats vaporizer 58. Combustion gases produced by burner 56 flow through vaporizer 58 via heat exchanging device 60, with cooled exhaust gases exiting vaporizer 58 by means of exhaust conduit 62. Vaporized working fluid from vaporizer 58 proceeds through vapor conduit 64 to turbine 66 causing turbine 66 to do work by rotation. Generator 67 coupled to turbine 66 converts the rotational work produced into electric power. As described above, in this embodiment, the electrical output of generator 67 is in the form of alternating current (AC) electricity. Rectifier 82 rectifies the AC output of generator 67 into a direct current (DC) output prior to the same being supplied to the AC load via an inverter. The expanded working fluid vapor exhausted from turbine 66 is supplied by expanded working fluid vapor exhaust conduit 68 to condenser 70. The expanded working fluid vapor is condensed in condenser 70 and the condensate produced is returned to vaporizer 58 through return conduit 71 via pump 72.

Although pump 72 is shown as not being connected to the turbine shaft of turbine 66, if preferred, this pump can be connected to the turbine shaft of turbine 66 so that such a pump is on the same turbine shaft as generator 67.

As has been stated above, it is an important aspect of this embodiment of the present inventive subject matter that primary power unit 16 may be, without limitation, a high temperature fuel

cell, a molten carbonate fuel cell (MCFC) while working fluid of the closed cycle vapor turbogenerator (CCVT) may be an organic working fluid.

Thus, it can be seen from the above description the present invention discloses a primary power unit, such as a high temperature fuel cell, e.g. a molten carbonate fuel cell, producing electric power that is supplied to a load, supplying approximately 85 - 95% of the load, and a secondary power unit in the form of a closed cycle vapor turbine (CCVT) system, which operates according to a Rankine cycle using organic working fluid, that is capable of producing approximately 5 - 15% of the electric power that is produced by the primary power plant and which is heated by rejected heat of the primary power plant. Consequently, by using such an arrangement, the full power requirements of the load are supplied by the hybrid ultra reliable power generating system during operation of the primary power unit.

Fig. 4 shows an example of a general layout diagram of such a power generating system. The vaporizer of the CCVT is operated by heat present in the hot exhaust gases of MCFC. As shown, preferably, the CCVT includes a burner that combusts the same fuel as the primary power plant and supplies sufficient heat so that the CCVT continues to produce approximately 5 - 15% of the power produced by said primary power plant to the load once the primary power plant stops operation.

In general, without limitation, an example of the power output levels of the combined hybrid ultra reliable power generating system is in the range of approximately 1 - 40 MW.

In addition, it should be noted that while in the above description, one primary power unit and one closed cycle vapor turbine (CCVT) are described in the each of the embodiments, more primary power units and more closed cycle vapor turbines (CCVTs) can be used in a single arrangement.

Thus, the present invention as herein described provides a high efficiency and reliable power generating system, which is attainable since the selected primary power units, e.g. MCFC, described herein achieve high efficiency levels and the secondary power units CCVT are adapted for producing power concurrently with the primary power units by using the heat present in the hot exhaust gases of a corresponding primary power unit, thereby resulting in a hybrid power generating system having a higher efficiency level than that of the primary power unit. In addition, the cost of electricity (per kW) of the hybrid power generating system is lower than that of the primary power unit. Furthermore, both the MCFC and CCVT systems have a relatively long life of approximately 20 - 30 years so that the power generating system will also have a relatively long life. Moreover, the secondary power unit CCVT provides this system with an ultra high level of reliability since it will continue to generate electricity upon

power outage of the primary power unit. Consequently, the number of required maintenance visits may be decreased relative to diesel generator systems. By using the system and method of the present invention, maintenance visits may be planned in advanced during normally acceptable working hours, rather than during weekends, nighttime or other inconvenient times, as carried out heretofore with prior art systems. Whereas relatively long periods of standby operation and unreliable startups, and consequently frequent maintenance visits, are characteristic of diesel generator systems, maintenance visits to the system of the present invention are not imperative during power outage of the primary power unit, since the secondary power unit CCVT will continue to operate and supply some of the electric power needed by the load. As maintenance is carried out to the primary power unit, operating costs consist only of usage of fuel for operating the secondary power unit.

It is believed that the advantages and improved results furnished by the method and apparatus of the present invention are apparent from the foregoing description of the invention. Various changes and modifications may be made without departing from the spirit and scope of the invention as described in the claims that follow.

16950/03
What is claimed is:

1. A hybrid ultra reliable power generating system comprising:

a) a primary power unit producing electric power that is supplied to a load; and

b) a secondary power unit in the form of a closed cycle vapor turbine (CCVT) system which is heated by rejected heat of the primary power unit and produces electric power that is supplied to a load, wherein working fluid in the vaporizer of the CCVT is heated by the heat rejected by the primary power unit,

the improvement of said power generating system being that said secondary power unit is capable of producing approximately 5 to 15% of the electric power that is produced by the primary power unit.

2. A hybrid power generating system according to claim 1 wherein the power produced by the primary power unit ranges from approximately 85 to 95% of the load.

3. A hybrid power generating system according to claim 1 wherein the power level of said system ranges from approximately 1 to 40 MW.

4. A hybrid power generating system according to claim 1 wherein said CCVT includes a burner that combusts the same fuel as supplied to the primary power unit and supplies sufficient heat so that the CCVT continues to produce approximately 5 to 15% of the

power produced by said primary power unit upon a power outage of the primary power unit.

5. A hybrid power generating system according to claim 1 wherein said primary power unit is a high temperature fuel cell.

6. A hybrid power generating system according to claim 5 wherein said primary power unit is a molten carbonate fuel cell.

7. A hybrid power generating system according to claim 1 wherein said CCVT is a closed cycle vapor turbine operating according to an organic Rankine cycle.

8. A method of generating continuous power using a hybrid ultra reliable power generating system comprising:

a) providing a primary power unit producing electric power that is supplied to a load; and

b) providing a secondary power unit in the form of a closed cycle vapor turbine (CCVT) system which is heated by rejected heat of the primary power unit and produces electric power that is supplied to a load, wherein working fluid in the vaporizer of the CCVT is heated by the heat rejected by the primary power unit,

the improvement of said method being that said secondary power unit produces approximately 5 to 15% of the electric power that is produced by said primary power unit.

9. A method according to claim 8 wherein the power produced by the primary power unit ranges from approximately 85 to 95% of the load.

10. A method according to claim 8 wherein the power level of the hybrid ultra reliable power generating system ranges from approximately 1 to 40 MW.

11. A method according to claim 8 further comprising the step of providing a burner that combusts the same fuel as supplied to said primary power unit and that supplies sufficient heat so that the CCVT continues to produce approximately 5 to 15% of the power produced by said primary power unit upon a power outage of the primary power unit.

12. A method according to claim 8 wherein the primary power unit is a high temperature fuel cell.

13. A method according to claim 11 wherein the primary power unit is a molten carbonate fuel cell.

14. A method according to claim 8 wherein said CCVT is a closed cycle vapor turbine operating according to an organic Rankine cycle.

לוצאטו את לוצאטו
LUZZATTO & LUZZATTO
By: ע"י

ORMAT

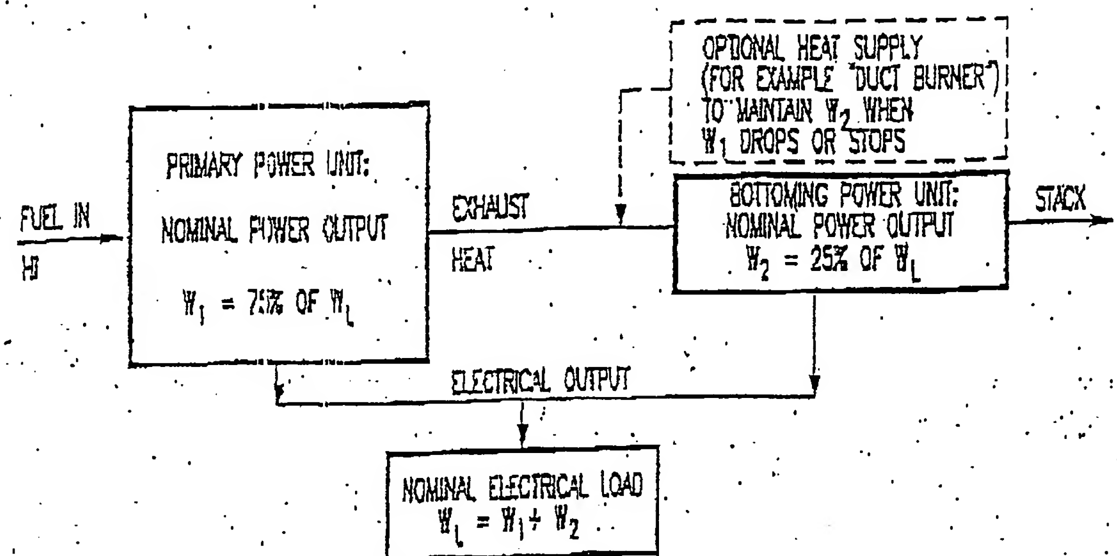
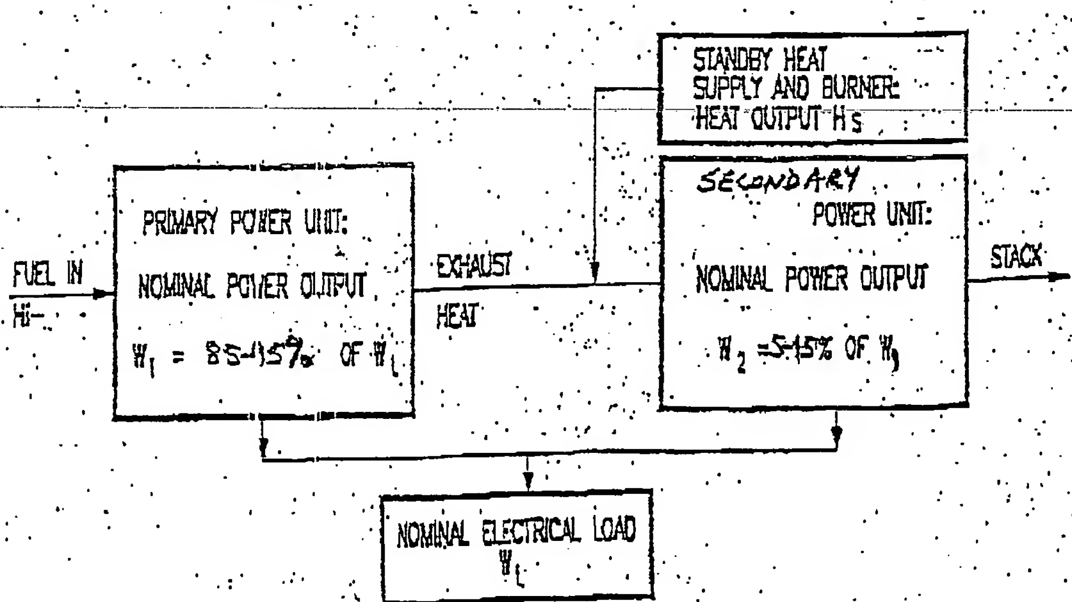


FIG. 1 PRIOR ART: CONVENTIONAL COMBINED CYCLE (TYPICAL)



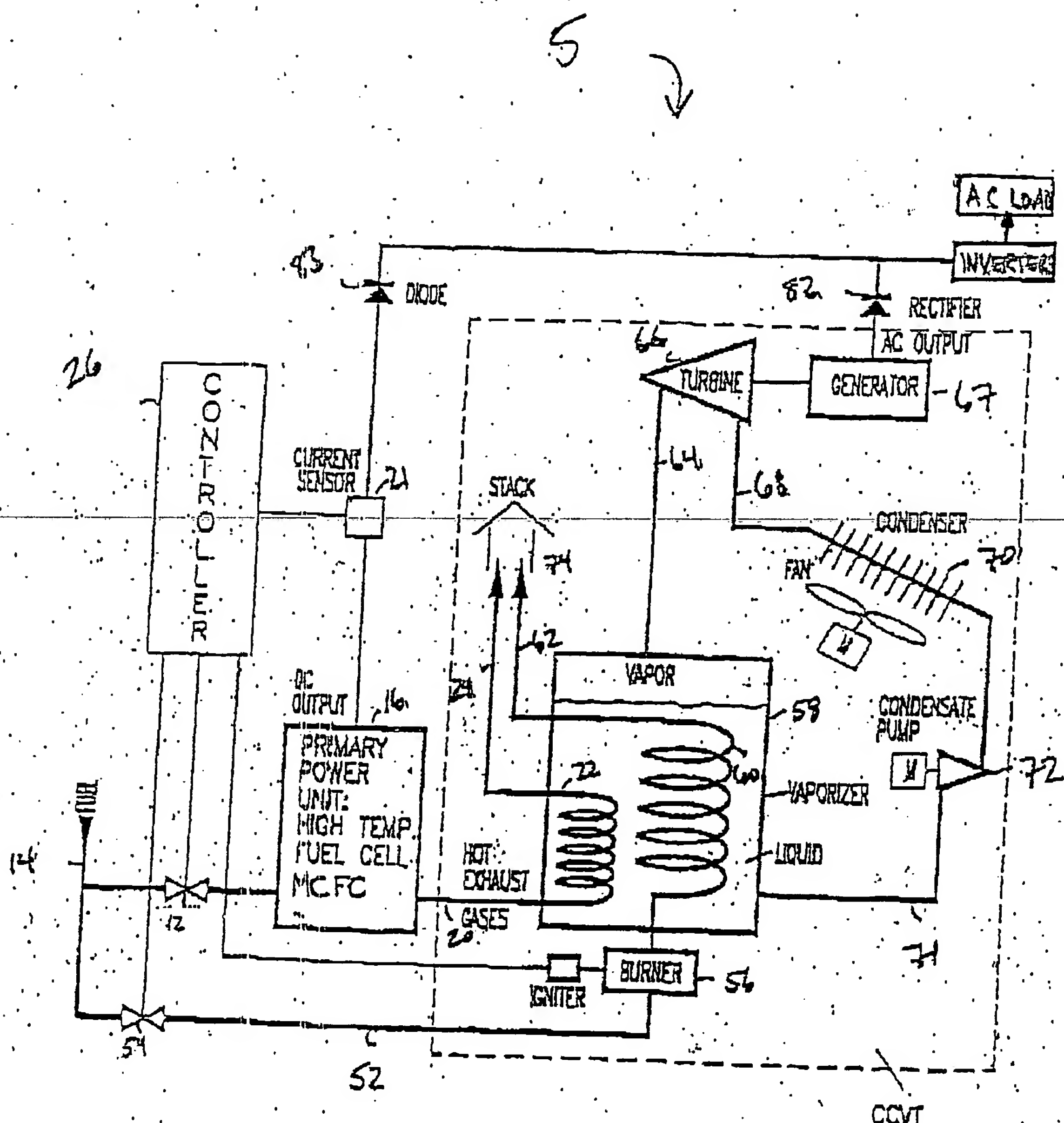
NORMAL OPERATION $W_L = W_1 + W_2$

$H_s = 0$

STANDBY OPERATION W_L = 5-15% OF W_1

W_2 = 5-15% OF W_1

FIG. 2 PROPOSED SYSTEM (EXAMPLE)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AC LOAD
INVERTER
43
DIODE
82
RECTIFIER
AC OUTPUT
66
TURBINE
GENERATOR
67
26
CONTROLLER
CURRENT SENSOR
21
STACK
64
68
CONDENSER
74
FAN
70
62
DC OUTPUT
16
24
VAPOR
58
CONDENSATE PUMP
PRIMARY POWER UNIT: HIGH TEMP. FUEL CELL MCFC
22
60
VAPORIZER
72
FUEL
14
LIQUID
HOT EXHAUST GASES
12
20
IGNITER
BURNER
56
71
54
52
CCVT

FIG. 3

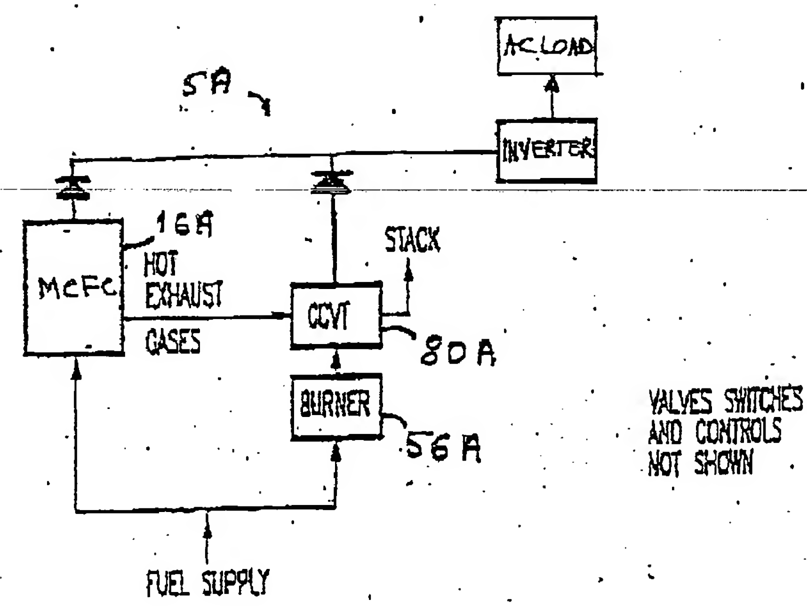
AC LOAD
5A
INVERTER
16A
McFC
HOT
EXHAUST
GASES
STACK
CCVT
80A
BURNER
56A
VALVES SWITCHES
AND CONTROLS
NOT SHOWN
FUEL SUPPLY

FIG. 4